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ABSTRACT

An irrelevant auditory probe procedure was employed to evoke brain event-related potentials (ERPs) in 56 right-handed Caucasian males while they learned concepts presented to them in study booklets. A mastery test was administered to assess concept acquisition. Subjects were divided into two groups according to whether or not their achievement test results were above or below the average score for all learners. A one-way multivariate analysis of variance (MANOVA) was computed for each presentation page employing as multiple dependent measures ERP amplitudes which corresponded to specific concepts. MANOVAs and their subsequent statistics revealed that, as theorized, ERPs evoked at the right frontal, temporal, and parietal, as well as the left parietal, regions, significantly distinquished below- from above-average concept learners. As hypothesized, poorer concept learners engaged these hemispheric sites less, and manifested more variability at them, than better learners. It was established that the frontal, temporal, and parietal areas, which are mainly implicated in crystalized intelligence, are engaged during the actual process of concept learning. (Author/DWH)

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Abstract

An irrelevant auditory probe procedure was employed to evoke brain event-related potentials (ERPs) in 56 males while they learned concepts presented to them in study booklets. A mastery test was administered to assess concept acquisition. Subjects were divided into two groups according to whether or not their achievement-test results were above or below the average score for all learners. A one-way multivariate analysis of variance (MANOVA) was computed for each presentation page employing as multiple dependent measures ERP amplitudes which corresponded to specific concepts. MANOVAs and their subsequent statistics revealed that as theorized ERPs evoked at the right frontal, temporal, and parietal, as well as the left parietal, regions, significantly distinguished below from above average concept learners. As hypothesized, poorer concept learners engaged these hemispheric sites less, and manifested more variability at them, than better learners. It was established that the frontal, temporal, and parietal areas which are chiefly implicated in crystallized intelligence are engaged during the actual process of concept learning itself.

Many studies have investigated relationships between brain event-related potentials (ERPs) and indices of intelligence. ERP latencies seem to vary inversely with measures of ability or intelligence (Bigum, Dustman & Beck, 1970; Callaway, 1973, 1975; Chalke & Ertl, 1965; Ertl, 1969, Ertl & Schafer, 1969; Galbraith, Gliddon & Busk, 1970; Gucker, 1973; Marcus, 1970; Shucard & Callaway, 1974; Shucard & Horn, 1972; Vogel, Broverman, & Klaiber, 1968). Yet some investigations failed to establish such a relationship (Barnet & Lodge, 1967; Engel & Fay, 1972; Henderson & Engel, 1974: Osborne, 1970; Rhodes, Dustman & Beck 1969). Right hemisphere ERP amplitudes and asymmetry measures appear to be directly related to intelligence--although not always (Bigum, Dustman & Beck, 1970; Galbraith, Glidden & Busk, 1970; Perry, McCoy, Cunningham, Falgout & Street, 1976; Rhodes, Dustman & Beck, 1969; Richlin, Weisinger, Weinstein, Giannini & Morganstern, 1971; Shucard & Horn, 1973). Other ERP properties that have been explored with respect to intelligence have been habituation (Barnet, 1971), variability (Bigum, Dustman & Beck, 1970; Callaway & Stone, 1969; Rhodes, Dustman & Beck, 1969), and harmonic components (Bennet, 1968; Ertl, 1971, 1973; Shucard & Callaway, 1974; Weinberg, 1969).

A number of experiments have been conducted to explore associations between different aspects of human information processing and brain electrical activity (e.g., Buchsbaum & Silverman, 1970; Donchin, 1975; Donchin & Cohen, 1967; Donchin, Kubovy, Kutas, Johnson & Hering, 1973; Federico, Froning &

Calder, 1983; Friedman, Guyer-Christie & Tymchuk, 1976; A. Hendrickson, 1982; D. Hendrickson, 1982; Hendrickson & Hendrickson, 1980; Horst, Johnson & Donchin, 1980; Isreal, Chesney, Wickens & Donchin, 1980; Isreal, Wickens, Chesney & Donchin, 1980; Lewis, Federico, Froning & Calder, 1981; Pizzamiglio, 1976; Ray, Morell, Frediani & Tucker, 1976; Robinson, 1982; Schafer, 1982; Schafer, Amochaev, & Russel, 1981; Shearer & Tucker, 1981; Squires, Petuchowski, Wickens & Donchin, 1977; Shucard, Shucard & Thomas, 1977; Tucker, 1981; Tucker, Shearer & Murray, 1977; Wickens, Mountford & Schreiner, 1981). Hardly any of these investigations reported relationships between ERPs, recorded while students are in the process of learning, and their subsequent achievement and performance. Are brain-wave measures associated with concept acquisition?

According to Snow (1980), Cattell's (1971) crystallized ability, G_c, represents a general dimension of measures that are good predictors of conventional educational achievement or scholastic ability (e.g., verbal, quantitative, vocabulary, reading comprehension, information, mathematical, and prior scholastic achievement). Cattell's (1971) fluid ability, G_f, represents another general dimension of measures that probably represents assembly and control processes necessary to structure adaptive strategies for solving novel and immediate problems (e.g., abstract, spatial, figural, and nonverbal reasoning tests).

In attempting to answer why G_c measures are often better predictors of learning than G_f measures, Snow (1980, p. 37) speculated:

> One reason may be that G_c represents the long-term

> accumulation of knowledge and skills, organized into functional cognitive systems by prior learning, that are in some sense crystallized as units for use in future learning. Because these are products of past education, and because education is in large part accumulative, transfer relations between past and future learning are assured. The transfer need not be of specific knowledge but rather of organized academic learning skills. Thus G_c may represent prior assemblies of performance processes retrieved as a system and applied new in instructional situations not unlike those experienced in the past, whereas G_f may represent new assemblies of performance processes needed in more extreme adaptations to novel situations. The distinction, then, is better long-term assembly for transfer to familiar new situations versus short-term assembly for transfer to unfamiliar new situations.

Federico (Note 1) and Federico, Froning, and Calder (1983) speculated that ERPs elicited in the frontal, temporal, and parietal regions of the brain are primarily indicators of crystallized intelligence, and those elicited in occipital regions are primarily indicators of fluid intelligence. Generally, they established that ERPs evoked in the frontal, temporal, and parietal areas were associated with general aptitude (i.e., comprehending language, solving arithmetic problems) and verbal and reading skill (i.e., understanding English words and prose passages), which are chiefly measures of crystallized

intelligence. ERPs evoked in the occipital areas were generally associated with spatial ability (i.e., manipulating spatial patterns), field dependence -independence (i.e., processing analytically versus globally), reflection-impulsivity (i.e., deliberating versus acting impulsively), tolerance of ambiguity (i.e., inclining to accept complex issues), and cognitive complexity (i.e., perceiving the environment in a multidimensional manner), which are chiefly measures of fluid intelligence.

Neuroanatomical substrates have been identified that contribute some support to this theory. Brodmann's segments 9, 10, 11, and 12 in the frontal lobe of the brain constitute association areas. These regions apparently project as well as receive a number of long, primary, association bundles that interconnect the different parts of each hemisphere (Goldman-Rakic & Schwartz, 1982; Grossman, 1967). Consequently, it is possible that these areas can readily interact or associate with practically all other segments of the cortex. These numerous interconnections could serve as the neuroanatomical analogue for crystallized intelligence: long-term storage of knowledge and skills, structured into functional cognitive systems by previous experience, established assemblies of performance processes retrieved as a system and used in new instructional situations similar to those of the past. Brodman s segments 17, 18, and 19 in the occipital lobe of the brain constitute cortical centers for vision and visual association. The numerous interconnections in these brain segments could serve as the neuroanatomical analogue for fluid intelligence: short-term assembly and control processes to structure adaptive strategies for solving novel and immediate problems in unfamiliar situations.

Therefore, it seemed reasonable to theorize that if ERPs evoked in the frontal, temporal, and parietal areas are chiefly implicated in crystallized intelligence, then these brain regions would be primarily employed and engaged during the actual process of concept learning itself. Futhermore, it was hypothesized that the extent and nature of the involvement of these three hemispheric regions during concept acquisition, as reflected by their corresponding ERPs, would significantly differentiate above from below average learners. It was speculated that poorer concept learners would engage the frontal, temporal, and parietal areas less, and would manifest more variability at these sites, than better learners. The purposes of this reported research were to (a) record ERPs as students learned typical concepts, and (b) determine if these ERPs were associated with their achievement.

Approach

Subjects. The subjects were right-handed, male, Caucasian recruits (N = 56) from the Naval Training Center, San Diego, who were undergoing basic enlisted military instruction. Audition of these volunteer subjects tested normal.

Instrumentation. Data were acquired on a field-portable computer system that included a Data General NOVA 2/10 central processing unit (CPU, 32K memory); a dual-drive floppy disk unit (Advanced Electronic Design, Inc., Model 2500); an optically isolated and multiplexing EEG unit with band pass set for 0.2-30 Hz; signal sampling rate for each channel of the analogue EEG waveforms was set at 500 Hz; and a videographic display unit, integrated into the CPU, that displayed the analyzed ERP data. Permanent storage of all video information was obtained from a video hard copy unit (Tektronix Model 4632) (Lewis, 1979,

Note 2, Note 3; Lewis & Rimland, 1979, 1980; Lewis, Rimland & Callaway, Note 4).

Stimuli. Auditory clicks were presented binaurally over headphones (Sennheiser Model 424X) periodically every 2 seconds. Click intensity was about 65 db (A) (Bruel and Kjaer Impulse Sound Level Meter, Model 2209, One-third Octave Filter Set, Model 1616). Headphone leads were shielded to minimize click artifacts. During all recording periods, white noise was used for masking. It was presented to the subjects through the headphones and via a speaker in the sound chamber at a level of approximately 50 db (A). This was done to create more uniform data acquisition conditions across all the subjects. The auditory click stimuli were presented over this background noise.

Recording Sites. Eight channels of auditory ERP were acquired from four pairs of homologous sites: sites F3 and F4 are over the frontal brain region, an association area; sites T3 and T4 are over the temporal region, a primary auditory reception area where many visual and auditory nerves interconnect; sites P3 and P4 are over the parietal region, a primary association area; and sites 01 and 02 are over the occipital region, a primary visual reception area (Jasper, 1958). Ground was at Pz in the mid parietal area. Sites designated by odd numbers denote left hemisphere locations; those designated by even numbers denote right hemisphere locations.

Electrodes. The subjects were prepared for recording after they had received brief instruction. They completed a short background questionnaire and signed a privacy act and volunteer consent form. An elastic helmet (Lycra) fitted with plastic holders for the electrodes was placed on the subject's head. Each

subject's hair was parted and scalp cleaned with an alcohol-impregnated swab that was placed through the holders. Electrode cream was placed down the holders and rubbed into the scalp. The electrodes were silver/silver chloride Beckman miniatures (actual surface contact area was 2mm) with a clear plastic extention tube (38 mm long) attached and filled with electrolytic solution. A small sponge (micro-cell foam) soaked with electrolyte held the solution in the tube and made contact with the electrode paste on the scalp. The extension tube not only held the electrode in place but also minimized the slow potential drift due to scalp temperature change that would have otherwise been picked up at the recording site. A Beckman mini-electrode fitted with a standard two-sided adhesive wafer served as a reference electrode on the nose. The helmet and all three electrodes could be attached in 6-8 minutes with impedance readings of 2-3K ohms. After all electrodes were in place, the subjects were instructed to observe their real-time EEG activity on the oscilloscope display. They were then instructed to move their jaws, eyebrows, etc., so that they could observe how muscle artifacts could contaminate the ERP data. The subject was then seated in a sound chamber in alignment with the video monitor. A hand-held switch allowed the subject to suspend all stimulus presentation and analysis operations to eliminate artifact. Additional artifact rejection was available by the console operator prior to storing the data.

ERP Data. ERPs were generated on-line, and the A/D digitization rate was one-quarter million samples per second. The auditory ERP data were retrieved from a floppy diskette and the required computations were performed. The data were then displayed on the video monitor and hardcopies were obtained. Eight

channels of auditory ERP data were overlayed in Figure 1. Standard deviation (SD) amplitude values are presented along the waveform mean values for the half-second post-stimulus epoch (512 msec). SD amplitude values (in uV) are normalized (waveform mean set to zero) RMS values (in uV). For all analyses, only SD amplitude values (in uV) were used. These values have have been found to be very effective when employing ERPs to study individual differences among many different kinds of subjects. There are individuals who do not manifest clearly defined ERP components. This index is also advantageous in that is permits the description of ERP amplitude as a single value (Callaway, 1975; Lewis & Froning, 1981). Calibration, polarity, DC offset, time base, and other descriptive information were also displayed. The waveforms from top to bottom were from the front to the back of the head at frontal, temporal, parietal, and occipital sites (F3, T3, P3, O1). Right hemisphere (RH) ERP data from sites F4, T4, P4, and O2 were presented in the right column.

Insert Figure 1 about here

Concept Learning Materials. Concept learning materials consisted of elementary ideas dealing with pulsed radar, e.g., radar components, pulse duration, pulse repetition frequency and interval, nautical mile, and distance a pulse travels in a microsecond. Figure 2 presents a sample of this concept learning subject matter.

Insert Figure 2 about here

Procedure. The concept learning materials were administered to each subject in a study booklet. An "irrelevant auditory probe" technique was used to elicit ERPs while the subjects actually studied the concept materials. Ten 65 db (A) clicks were administered to a subject as he learned each new page of concepts. These auditory probes were presented randomly with an averaged inter-stimulus interval of approximately 1.5 sec. Subjects were allowed a maximum of 30 sec. per page to acquire the concepts. Subjects were asked to read each page of concept materials to learn it, for they would be tested shortly thereafter on their acquisition of basic radar notions. The concept materials consisted of 12 numbered study pages. The experimenter could synchronize the ERP recordings with a subject's acquisition of the concept learning materials by cuing on the large page numbers. The achievement test for concept learning consisted of ten, five-alternative, multiple-choice, objectives-referenced items. Each item was scored 1 for correct, and 0 for incorrect. The total test score was simply the number of correct items. The basic pulsed radar concepts administered to the subjects together with their corresponding presentation pages and test items are listed in Table 1.

Insert Table 1 about here

Subjects were divided into two groups based upon whether their total concept achievement score was above or below the mean. Using these defined groups, thirteen, one-way, multivariate analyses of variance were computed using as

input the ERPs recorded per page and those obtained across all pages of concepts.

Results

The means and standard deviations for each item of the concept criterion test are presented in Table 2 for the reader's inspection.

Insert Table 2 about here

Statistics associated with the discriminant functions (eigenvalues, canonical correlations, Wilks' lambda, chi-squared, and group centroids, respectively), using ERP amplitudes obtained for each page of concepts to separate the subjects below from those above the mean-concept-total score (X_c = 4.55, s_c = 2.01), revealed that three derived discriminant functions significantly distinguished between these two groups. These functions employed ERPs obtained during the learning of pages 7, 8, and 11 which dealt with concepts of how many yards in a nautical mile, and a microsecond of radar range equals how many yards, respectively:

(a) for page 7, = .44, R_c = .55, = .70,

(8) = 18.14, p = .02, C_b = .67, C_a = -.63;

(b) for page 8, = .40, R_c = .53, = .72,

(8) = 16.80, p = .03, C_b = .64, C_a = -.60; and

(c) for page 11, = .50, R_c = .58, = .67,

(8) = 20.23, p = .01, C_b = .72, C_a = -.67.

Standardized discriminant coefficients, univariate F-ratios, means and standard deviations for each group were computed using ERP amplitudes corresponding to concepts on pages 7, 8, and 11. In terms of the relative magnitude of the discriminant coefficients, which reflect all the ERP amplitudes interacting together in a multivariate manner to separate the groups, the more important brain sites for contributing to the significant discriminant functions were:

(a) for page 7, the right temporal and occipital areas
(d = 1.50, -1.54, respectively);

(b) for page 8, the right parietal region (d = 1.19); and

(c) for page 11, the left and right parietal areas
(d = 2.65, -3.0, respectively).

Taking each ERP alone, i.e., without it interacting in a multivarite fashion with others obtained per page of concepts, the univariate F's, and group means and standard deviations revealed:

(a) the right temporal ERP significantly differentiated the group below the mean total concept score from the group above the mean total, with the former having higher mean amplitude and larger standard deviation than the latter:

(i) for page 7, $F(1,54) = 6.09$, $p = .02$, $X_b = 3.48$,
$X_a = 2.71$, $s_b = 1.40$, $s_a = .90$;

(ii) for page 8, $F(1,54) = 5.46$, $p = .02$, $X_b = 3.14$,
$X_a = 2.56$, $s_b = 1.04$, $s_a = .83$, respectively.

(b) the right frontal ERP significantly differentiated the group below the mean total concept score from the group above the mean total, with the former

also having higher mean ERP amplitude and larger standard deviation than the latter:

(i) for page 11, $F(1,54) = 5.97$, $p = .02$, $X_b = 3.40$,

$X_a = 2.80$, $s_b = 1.14$, $s_a = .64$, respectively.

DISCUSSION AND CONCLUSIONS

The results established that some ERPs, recorded as students were in the process of learning concepts, seemed to be related to subsequent achievement. Several ERPs were able to discriminate significantly below from above average concept learners. Considering ERPs to interact statistically in a multivariate manner, ERPs evoked at the right temporal, parietal, and occipital and left parietal regions distinguished the below from the above average concept-learning group. Subsequently, regarding ERPs singlely or univariately, ERPs triggered at the right frontal and temporal areas significantly differentiated the groups. At these two brain sites, the below average concept learners had higher mean ERP amplitudes and larger standard deviations than those above average. It appeared that poorer concept learners engaged the right frontal and temporal regions less, and were more variable at these sites, than the better learners. Possibly, the former processed less concept-related information at these brain locations than the latter. This study demonstrated that the right frontal, temporal, and parietal areas are significantly associated with concept learning -- not only left hemisphere regions as proposed in the popular asymmetric model of the brain.

A few of the findings of this research, which used auditory stimuli to evoke ERPs, were somewhat consonant with Lewis and Rimland's (1976) results that

right frontal and left parietal amplitudes, elicited by visual stimuli, were associated with predicting success in a remedial reading program. Lewis, Rimland, and Callaway (Note 4) suggested that left parietal amplitudes triggered by visual stimuli are related to general aptitude and intelligence. These previous findings are only partially compatible with some of the results reported in this study since different stimuli were used to evoke cortical responses. Lewis and Froning (1981) demonstrated that the left parietal and right temporal areas discriminated between high and low reading groups using visual ERPs. Their investigation, together with the present study, indicated the importance of these sites for reading skill or comprehending concepts.

This experiment demonstrated the importance of the right frontal, temporal, parietal, and occipital regions, together with the left parietal area, for acquiring concepts. These results are like some of Federico, Froning, and Calder's (1983) findings regarding auditory ERPs which revealed that the right frontal and temporal and left frontal regions are negatively related to reading skill and logical reasoning, based upon individual product-moment correlations. Also, the results of this study are somewhat similar to Lewis, Rimland, and Callaway's (Note 4) finding that asymmetry at the parietal areas significantly distinguished between high and low general aptitude groups. In this reported research asymmetry measures were not derived; nevertheless, ERPs in the left and right parietal regions did contribute to the significant discrimination between below and above average concept learners. Molfese, Papanicolau, Hess, and Molfese (1979), however, identified components of the auditory evoked responses in the left and right temporal regions which were sensitive to

semantic and conceptual processes. Also, Chapman (1977), using stimulus words, which had been scaled according to the semantic differential technique (Osgood, Suci & Tannenbaum, 1957), to evoke potentials recorded between brain sites Pz and Cz, provided evidence that two types of semantic properties could be independently identified in ERPs: (a) the semantic class of stimulus words (positive or negative evaluation, potency, or activity), and (b) the semantic dimension employed to judge stimulus words.

Unlike the Federico, Froning, and Calder (1983) study, ERPs in this reported investigation were recorded while subjects actually engaged in a concept acquisition task. Each subject's involvement in the learning task had been adequately motivated and closely monitored to assure his continuous cognitive processing of the textual information presented during the ERP recording session. During this period, irrelevant auditory tones were superimposed upon ongoing prose processing. Possibly, the right hemisphere sites involved were more engaged or activated by the processing requirements of the concept learning task and superimposed auditory probes, than they were by the separate processing of only visual or auditory stimuli used in the Federico, Froning, and Calder study to elicit ERPS. It seems that this speculation would have been especially true for above average concept learners.

It should be noted, however, that Shucard, Shucard, and Thomas (1977) found that the left temporal region responded with lower ERP amplitude than the corresponding right to irrelevant auditory probes while subjects were engaged in a verbal processing task. They speculated that in the engaged hemisphere, fewer neurons would probably be available to respond to the probe stimulus.

Consequently, this would have produced a low amplitude ERP at the involved hemispheric site. The findings of this present study, together with those of others (e.g., Doyle, Ornstein & Galin, 1974; Galin & Ellis, 1975; Galin & Ornstein, 1972, Shucard, Shucard & Thomas, 1977) substantiate further the hypothesis that brain hemispheres can respond intermittently and function independently of one another.

In summary, this study established that ERPs elicited in the frontal, temporal and parietal areas, which are speculatively implicated in crystallized intelligence, are engaged during the actual process of concept acquisition. Furthermore, this experiment demonstrated that the degree and nature of the involvement of these hemispheric regions during concept learning, as indicated by their respective ERPs, significantly distinguished below from above average concept learners. As hypothesized, poorer concept learners engaged the frontal, temporal, and parietal areas less, and were more variable at these sites, than better learners. Evidently, those hemispheric regions theoretically linked to concept acquisition are indeed involved in the learning process itself.

Footnotes

1. Opinions and assertions contained herein are those of the author and are not to be construed as official or reflecting the views of the Department of the Navy or Defense.

2. Requests for reprints should be sent to Pat-Anthony Federico, Code P51, NPRDC, San Diego, CA 92152

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Table 1

Test Item, Presentation Page(s), and Corresponding Concepts

Test Item	Presentation Page(s)	Concept
1	1,2	Five Basic Components of Radar
2	3,4	Pulse Duration Definition
3	5	Pulse Repetition Frequency (PRF) (definition)
4	5	PRF (measurement)
5	6	Pulse Repetition Interval (PRI) (definition)
6	6	PRI (measurement)
7	6	PRF/PRI Relationship
8	7,8	Number of Yards in a Nautical Mile
9	9,10	Number of Yards a Pulse Travels in a Microsecond
10	11,12	Radar Range per Microsecond

Table 2

Means and Standard Deviations for Each Item of the Concept Criterion Test

Item	$\bar{X}$	s
1	.71	.46
2	.41	.50
3	.38	.49
4	.14	.35
5	.39	.49
6	.16	.37
7	.54	.50
8	.64	.48
9	.61	.49
10	.61	.49

N = 56

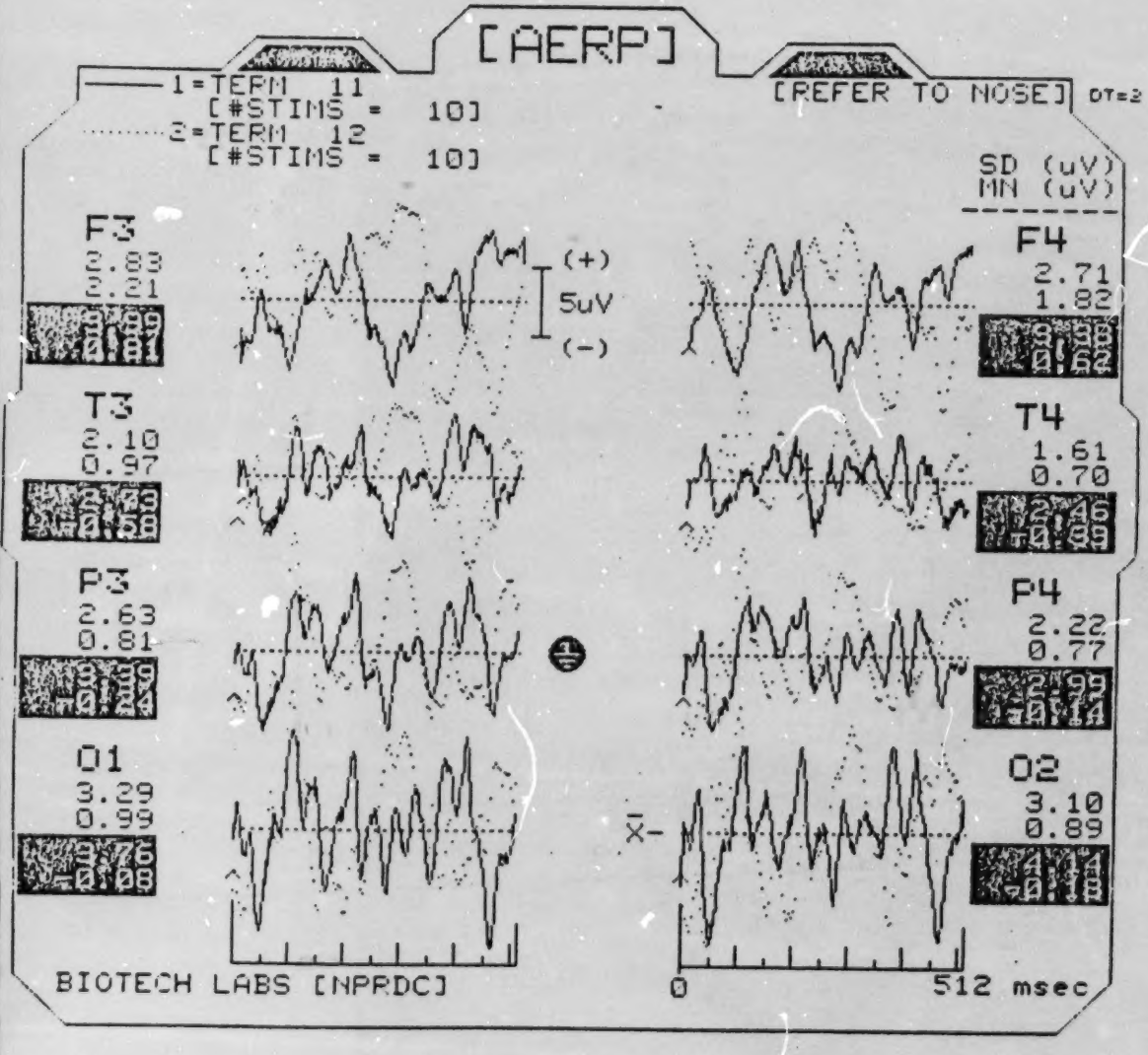

Figure 1. Example ERP overlay for eight channels.

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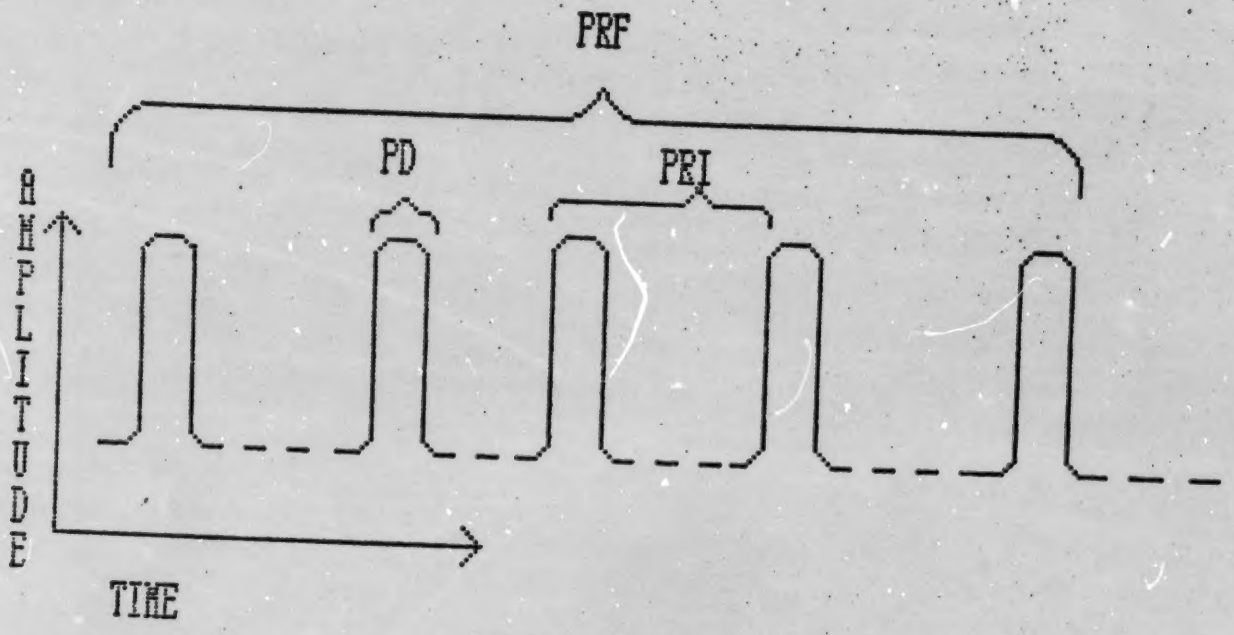

DEFINITION OF THE TERM: PULSE REPETITION FREQUENCY (PRF)
PRF is defined as the number of times a radar is pulsed on each second. PRF is, therefore, the count of the number of pulses transmitted per second (PPS).

Figure 2. Sample of concept learning subject matter.